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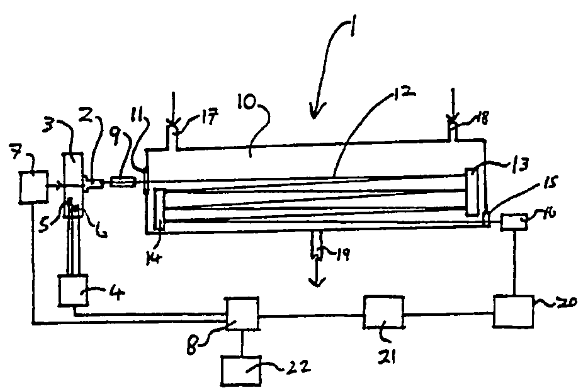
(54) An optical absorption oxygen sensor

(57) An optical absorption oxygen sensor 1 employs a pulsed laser diode 2 passing laser energy through a gas sample to the photo detector and measuring the received intensity of the laser light at the photo detector 16. The temperature of the laser diode is stabilised at a value such that the self induced change in laser output frequency during each pulse sweeps the laser output frequency across an oxygen absorption line.

Fig1



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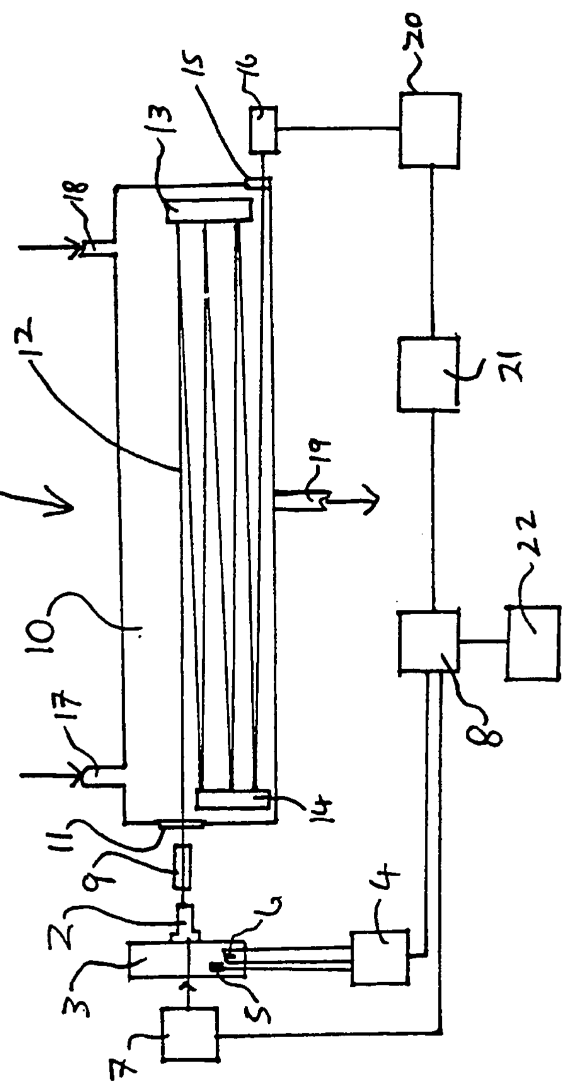

Fig1

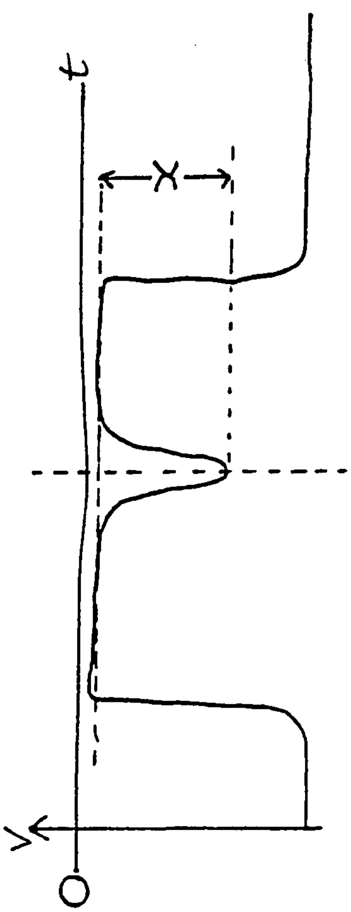

Fig2

OXYGEN SENSOR

This invention relates to an oxygen sensor, and particularly to an optical absorption oxygen sensor.

Known oxygen sensors employ electro chemical cells in order to sense oxygen concentration, these have a relatively low accuracy and stability, requiring regular calibration. This low accuracy and stability is a considerable problem in designing suitable sensors for gas analysis and particularly in exhaust gas analysis systems for motor vehicles.

Most gasses can be satisfactorily sensed using optical absorption techniques but it has not been possible to design a satisfactory optical absorption oxygen sensor because of the structure of oxygens absorbtion spectrum.

The near infra red absorption spectrum of oxygen gas at atmospheric pressure consists of some twenty principal absorption lines each having a width of about 0.006 nanometres and being spaced apart by about 0.1 nanometres, this group of lines being at around 760 nanometres wavelength.

As a result it is difficult to produce an optical absorbtion oxygen sensor because the precise emission frequency of a laser diode varies with temperature. This means that small temperature changes in the environment around the sensor will cause the emission frequency of the laser to alter sufficiently to put it outside one of these

absorbtion lines.

In theory it would be possible to keep a laser diode precisely tuned to a specific oxygen absorbtion line by very accurate control of its temperature, but in practice the degree of accuracy to which the temperature must be controlled is so high that this has not been attempted due to the difficulties and costs involved.

This invention was intended to provide a optical absorption oxygen sensor.

This invention provides an optical absorption oxygen sensor comprising a pulsed laser and a photo detector arranged so that light emitted by the laser passes through an oxygen sensing region to the photo detector in which the self induced change in laser emission frequency during each pulse is employed to sweep the laser output frequency across an oxygen absorption line.

The use of the self induced change in laser emission frequency during each pulse to sweep the output frequency of the laser across an oxygen absorbtion line greatly simplifies the design of the oxygen sensor by reducing the degree of accuracy of temperature control required because the temperature of the laser need only be stabilised with sufficient accuracy to ensure that the selected oxygen absorbtion line is within the frequency range swept by the output of the laser.

An oxygen sensor employing the invention will now be described with reference to the accompanying diagrammatic figures, in which;

Figure 1 shows an oxygen sensor embodying the invention, and

Figure 2 shows an example of the output signal from a part of the sensor of Figure 1.

Referring to Figure 1 an oxygen sensor 1 is shown. The oxygen sensor 1 comprises a laser diode 2 mounted on a temperature controlled block 3. The temperature of the temperature controlled block 3 is controlled by a temperature controller 4 which receives temperature information from a thermal sensor 5 mounted within the block 3 and supplies power to a heating coil 6, also mounted within the block, in response to the signals from the thermal sensor 5 to keep the temperature of the block 3 approximately constant at pre-set level.

The precise frequency of the laser light emitted by a nominally 760 nanometre laser diode depends on its temperature and it has been found that when such a laser diode is operated in a pulsed mode the emitted frequency changes significantly during the pulse due to the temperature changes induced within the diode by the input power causing it to lase. It has been found, for example, that in a Sharp single frequency laser diode type LTO31MD having a nominal emission wavelength of 760 nanometres modulated with a 1 KHz squarewave an emitted wavelength shift of 0.2 nanometres is observed during each pulse. The phenomenon of a signal pulse which changes in frequency during the pulse is referred to as a chirp.

Although it would, in theory, be possible to temperature tune a laser diode to

a single oxygen absorption line this requires that the temperature be very precisely controlled and it has been realised that this temperature control accuracy requirement can be greatly reduced and the construction of the optical sensor greatly simplified by using the self induced chirp of the laser diode to sweep the laser frequency across a selected oxygen absorption line.

The laser diode 2 is driven by a laser driver 7 which is in turn controlled by a processor 8. The light emitted by the laser diode 2 passes through a lens system 9 and into a gas cell 10 through a first window 11. The light emitted by the laser 2 then follows a path 12 bouncing repeatedly between a first plane mirror 13 and a second plane mirror 14 and finally exiting the gas cell 10 through a second window 15. The laser light leaving the gas cell 10 is incident on a photodiode 16 which generates an electrical signal corresponding to the intensity of the incident light.

The gas mixture whose oxygen content is to be measured is passed into the gas cell 10 through two inlets 17 and 18 and passes out of the gas cell 10 through an outlet 19.

The gas outlet 19 is situated midway along the gas cell 10 and the two gas inlets 17 and 18 are situated near the ends of the gas cell 10 equidistant from the gas outlet 19 and on the opposite side of the gas cell 10 from it in order to minimise turbulence within the gas cell 10 and ensure that the whole of the gas cell 10 is quickly filled by the gas sample entering through the inlets 17 and 18 as it displaces the gas already in the cell.

The gas sample supplied to the gas cell 10 will need to be filtered to remove particles which could dirty the optics in the gas cell 10 or cause the opacity within the gas cell 10 to rise to unacceptable levels, such filtration is normal in optical gas sensors and need not be described in detail here.

The output signals generated by the photodiode 16 are passed to a pre-processor 20 which clamps the peak output from the photodetector to zero volts and this clamped output from the pre-processor is then converted into a digital signal by an A to D converter 21 and then supplied to the processor 28. It would be possible to A to D convert the signal from the photodiode directly without pre-processing but this would require an A to D converter operating to a greater number of bits to acheive the same resolution of oxygen concentration because the A to D converter would have to operate over a greater possible range of analogue signal voltage values.

In operation the gas whose oxygen concentration must be sensed is passed through the gas cell 10 and the laser driver 7 triggers a laser pulse from the laser diode 2 and the processor 8 is simultaneously informed by the laser driver that this pulse has been produced. The pulse passes along the optical path 12 to strike a photodiode 16 and the resulting output of the photodiode is clamped by the pre-processor 20, digitised by the A to D converter 21 and supplied to the processor 8 as a string of 500 digital samples. Because of the chirping effect explained above, during operation of the laser diode 2 the frequency of the laser light emitted by the diode 2 will have altered during the pulse. The intensity of the light emitted by the laser during each pulse will decay exponentially with time during the pulse, however correction for

such exponential decay is simple and is commonly carried out in many signal processing applications and can easily be acheived in the processor 8 by any one of a number of known methods.

Due to the change in frequency during the pulse the absorption co-efficient of the gasses within the gas cell 10 will appear to vary during the pulse as the change in frequency moves across the oxygen absorbtion line. As a result the digital signal received at the processor 8 has the form shown in Figure 2 after compensation for the exponential decay in intensity. Because the pre-processor 20 clamps the input signal from the photodiode 16 to zero volts, an ouput of zero volts corresponds to no absorption in the gas cell 10, as a result the output is a substantially square pulse with a trough where the emission frequency of the laser diode 2 coincides with an oxygen absorption line. The processor 8 calculates the mean level of the compensated digitised signal based on the signal values on either side of the trough and finds the point of inflexion which is at the bottom of the trough. The processor 8 then measures the difference x between the mean value and the value at the point of inflexion. This difference in value is then scaled by dividing it by the mean value to give a number proportional to the absorbtion per unit length along the optical path 12 and thus to the concentration of oxygen in the gas cell 10. The exact proportionality will depend upon the precise design of the system but can be easily measured and the appropriate proportionality constant permanently embedded in memory within the processor 8. The number produced can then be multiplied by the proportionality constant to provide an oxygen concentration output to the visual display unit 22.

It is of course if necessary that the same oxygen absorption line is used at all times in order for the proportionality constant to produce correct oxygen concentration values and to this end the temperature controller 4 uses the temperature data from the temperature sensor 5 to keep the temperature of the block 3 and thus the temperature of the laser diode 2 at the start of each pulse constant by varying the power supplied to the heating coil 6. In this way the temperature, and thus the emision frequency, of the laser diode 2 can be kept sufficiently constant that during each emitted pulse its emission frequency will sweep across the same oxygen absorption line.

In order to increase the sensitivity of the oxygen sensor further the position in time of the absorption notch in the output of the photodiode 16 relative to the start of each output pulse could be measured by the processor 8 and the temperature of the block 3 and laser diode 2 fine tuned by the processor 8 instructing the temperature controller 4 to stabilise the temperature of the block 3 at a different temperature so as to keep the notch at some preset time value within the pulse. This would increase the accuracy of the system by removing any second order factors in the emitted laser amplitude which would cause the apparent absorption to vary slightly from pulse to pulse if the minimum was allowed to occur at different points in the pulse.

Although the system described above always uses the same oxygen absorbtion line it would be possible to alter the temperature of the laser diode so that it swept over different absorbtion lines provided the appropriate proportionality constant for each absorbtion line used was available.

In the example the minors 13 and 14 are planar, alternatively one of them could be a concave spherical mirror having a long radius of curvature in order to reduce the alignment tolerance requirement of the mirrors and periodically refocus the laser beam to keep its diameter small. The radius of curvature would be longer than the separation of mirrors 13 and 14.

CLAIMS

1. An optical absorption oxygen sensor comprising a pulsed laser and a photo detector arranged so that light emitted by the laser passes through an oxygen sensing region to the photo detector in which the self induced change in laser emission frequency during each pulse is employed to sweep the laser output frequency across an oxygen absorption line.

2. A sensor as claimed in claim 1 in which the laser is a laser diode.

3. A sensor as claimed in claim 1 or claim 2 in which temperature control means are provided to keep the temperature of the laser at the start of each pulse stable at some preset value.

4. A sensor as claimed in any preceding claim in which the same oxygen absorption line is always used.

5. An optical absorption oxygen sensor substantially as shown in or as described with reference to the accompanying Figures.

Patents Act 1977 **Examiner's report to the C[redacted]troller under Section 17** **(T. Search report)**	A[redacted]lication number C[redacted]02212.6
Relevant Technical Fields (i) UK Cl (Ed.M) GIA (ACDA, ACDG, ACDX) (ii) Int Cl (Ed.5) G01N G01J	Search Examiner S J MORGAN Date of completion of Search 19 APRIL 1994
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE DATABASE WPI	Documents considered relevant following a search in respect of Claims :- 1-4

Categories of documents

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&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
X	WO 87/07018 A1 (HIBSHAM CORP) See whole document	1-4

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